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HIGH RESOLUTION UV SPECTROSCOPY OF H_2 AND N_2 APPLIED TO OBSERVATIONS OF THE PLANETS BY SPACECRAFT

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The next generation of high resolution UV imaging spacecraft are being prepared for studying the airglow and aurora of the Earth, the other terrestrial planets and the Jovian planets. To keep pace with these technological improvements we have developed a laboratory program to provide electron impact collision cross sections of the major molecular planetary gases (H_2, N_2, CO_2, O_2 and CO). Spectra under optically thin conditions have been measured with a high resolution ($\lambda/\Delta\lambda \approx$ 50000) UV spectrometer in tandem with electron impact collision chamber. High resolution spectra of the Lyman and Werner band systems of H_2 have been obtained and modeled. Synthetic spectral intensities based on the J-dependent transition probabilities that include ro-vibronic perturbations are in very good agreement with experimental intensities. The kinetic energy distribution of H(2p,3p) atoms resulting from electron impact dissociation of H_2 has been measured. The distribution is based on the first measurement of the H Lyman-u (H Lα) and H Lyman-β (H Lβ) emission line Doppler profiles. Electron impact dissociation of H2 is believed to be one of the major mechanisms leading to the observed wide profile of H Lα from Jupiter aurora by the Hubble Space Telescope (HST). Analysis of the deconvolved line profile. of H Lα reveals the existence of a narrow line peak (40 mÅ FWHM) and a broad pedestal base (240 mÅ FWHM). The band strengths of the electron excited $N_2(C\,^3\Pi_u - B\,^3\Pi_g)$ second positive system have been measured in the middle ultraviolet. We report a quantitative measurement of the predissociation fraction $0.15\pm^{.01}_{.045}$ at 300 K in the N2 $c_4'\,^1\Sigma_u^+ - X\,^1\Sigma_g^+$ (0,0) band, with an experimental determination of rotational line strengths to be used to understand N_2 EUV emission from Titan, Triton and the Earth.

1.0 INTRODUCTION

Since the launch of HST there have been many investigations of the aurora and dayglow phenomena of Jupiter by observing the far-ultraviolet (lWV) emission spectra of electron excited H_2 [1]. This paper describes the analysis of the high resolution optically thin Lyman and Werner band systems and the line profile of H La and H Lβ with a newly constructed three meter spectrometer ((k/AL, ≈ 50000). Analysis of the high resolution spectra of the H_2 band systems yields refinements of a previous model of the excitation of hydrogen by electrons. Previous models of the H_2 band systems applied to laboratory, astrophysical and planetary emission systems contain minimal correction for perturbation [2]. In addition, the J-dependence of electronic transition moment was neglected.

For many years high resolution studies have been carried out on the Balmer series (principal quantum number, n=3, 4 and 5 excited states) of H produced by dissociative excitation of H_2 upon electron impact. For each principal quantum number, two major sets of kinetic energy distributions were found, corresponding to the "slow" and "fast" distributions with typical kinetic energies of near O eV and 4-10 eV, respectively. The principal architects of these measurements were Ogawa and co-workers [3]. They have carefully shown that the two kinetic energy distributions reflect effects of dissociation from singly excited bound states (slow component) and from repulsive doubly excited states (fast component). Recently, wc have begun high resolution studies of the Lyman series of H from dissociative excitation of H_2 [4]. We reported the first measurement of the H La emission Doppler profile from dissociative excitation of H_2 by electron impact. Slow H(2p) atoms with peak energy near 80 meV produce the peak profile, which **is nearly independent of impact energy. The** energy distribution of the fast atoms shows a peak at about 4 eV. We extend the measurements to the 3p state and compare our results to line profile studies of ha.

We also report that the fine structure of the $N_2\ c_4'\ {}^1\Sigma_u^+ - X\ {}^1\Sigma_g^+$ (0,0) band has been analyzed in optically thin laboratory emission spectra obtained from crossed electron and N_2 beams. The distortion of the rotational envelope from calculations based on constant rotational level radiative transition probabilities has been used to obtain the predissociation yield as a function of J-level. The $N_2\ c_4'\ {}^1\Sigma_u^+ - X\ {}^1\Sigma_g^+$ (0,0) band system is important since it has 'the largest excitation cross section of N_2 in the extreme ultraviolet (EUV) [5]. The only identification of this band, showing significant strength has been obtained in the EUV spectrum of Titan [6]. The N_2 ($c_4'(0)$) vibronic level is known to be mixed with several nearby states and the rotational energy distribution shows strong evidence of perturbation by the b'' ${}^1\Sigma_u^+$ -state [7].

The N_2 ($C\ {}^3\Pi_u - B\ {}^3\Pi_g$) second positive system 2PG (0,0) band at 3371.4 Å is used as a monitor of the photoelectron flux in the terrestrial dayglow and secondary electrons in the aurora. The 2PG is chosen for this role since its emission cross section peaks at low energy (10-15 eV). In this region the 2PG(0,0) band excitation function displays structure from N_2^- resonances that decay to the $C\ {}^3\Pi_u$ state by autoionization and collisional cascade from the $E\ {}^3\Sigma_g^+$ state. Inversion of the 2PG(0,0) band emission intensities to infer atmospheric electron energy distributions requires accurate excitation cross sections in the threshold region.

2.0 EXPERIMENTAL

The experimental system has been described [8]. In brief, the experimental system consists of a high-resolution 3-meter uv spectrometer in tandem with an electron impact collision chamber. The line shapes and spectra were measured with experimental conditions that ensure linearity of signal with electron beam current and background gas pressure.

3.0 H_2 LYMAN AND WERNER BAND SYSTEMS

We show in Fig. 1a an overplot of the high resolution H_2 spectrum at 100 eV electron impact energy (solid line) and the convolved spectrum based on the transition probabilities of Allison and Dalgarno [9]. It is clear that several prominent synthetic spectral features differ significantly from the experimental conditions in both position and intensity. All the transitions between 1227 and 1236 Å appear to be shifted to

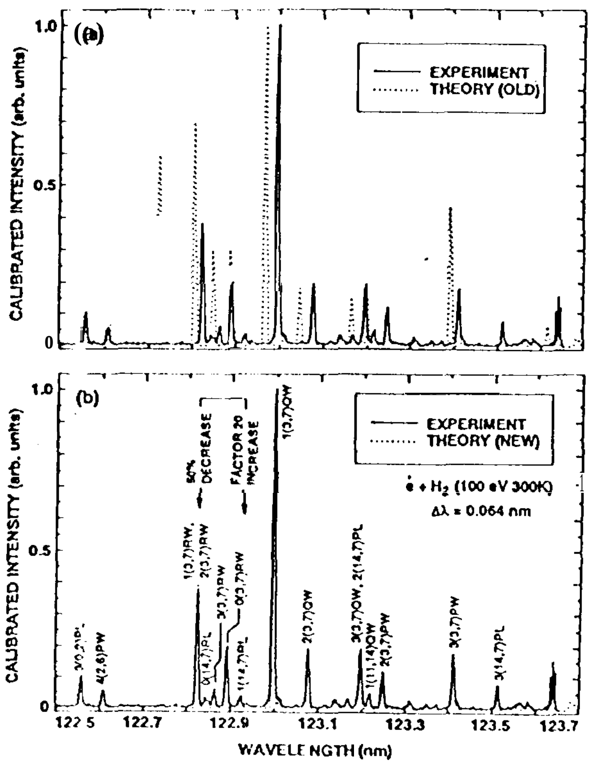

Figure 1. Comparison between experimental data and model: (a) using transition probabilities of Allison and Dalgarno with Honl-London factors (b) using transition probabilities of Abgrall et al. PL refers to P- branch of Lyman system, etc.

the blue. In general, the model underestimates the relative intensity of the Lyman (14,7) band and overestimates that of the Werner (3,7) band. The intensity and position discrepancies can be explained. First, *ab initio* calculations [10] shows that misassignments have occurred in the FUV. For example, J=1,2 of v'=3 needs to be interchanged with J=1,2 of v'=14. Second, calculations have shown that v'=3 of the C-state and v'= 14 of the E-state are strongly coupled for J=1,2. Moreover, the spontaneous radiative transition probabilities differ from the ratios of Honl-London factors. Good agreement between the experimental and synthetic spectra is shown in Fig. 1b, demonstrating thc accuracy of the calculations including rotational-vibrational coupling, bascd on the transition probabilitics of Abgrall ct al. [10].

4.0 LINE PROFILES FOR H La AND H Lβ

The electron -impact -induced-ftuorcsccncc linc profiles of H La and H Lβ at 100 cV impact encrgy are shown in Fig. 2a. As cxpcctcd at 100

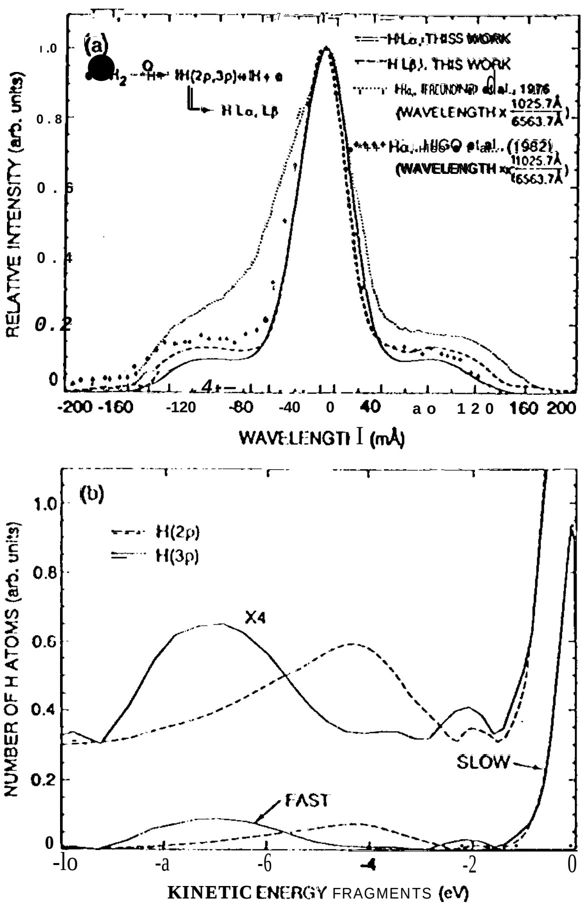

FIGURE 2. a) The dcconvolution of the H La and H Lβ linc profiles.
b) Slow and Fast fragment H(2p,3p) kinctic energy distributions at 100 CV from "bluc" wing.

cV, the line profiles consists of a narrow central peak and a broad wing base. The mcasured FWHM of 49 mÅ for H Lα is not narrow with respcct to the instrumental slit function (FWHM = 24 mÅ). Fast Fouricr Transform (FFT) techniques wcre used to rccovcr the actual line profile. The measured line profile is the convolution of the true line profile and the instrumental slit function. Wc show in Fig. 2 the inverse FFT (FFT^{-1}) of the 100 cV linc profile. The dcconvolvcd linc profile of the central peak is found to have a FWHM of 40 ± 4 mÅ for the 100 cV H Lα line profile.

In addition, wc show in Fig 2a the FFT^{-1} for the H Lβ linc profile along with two published line profiles for Hα [11,1'21. Other work on Hα was performed by Ito ct al [131. For the Hα multiplets the line profile would bc idcntical to Lβ whcn scaled in wavelength by the factor 1025.7A /6563.7Å, according to the Dopplcr principle.

The combincd kinctic energy distributions of the fast and slow H(2p) and H(3p) fragments arc shown in Fig. 2b. The results for the H(3p) atom distribution show a peak kinctic energy at 7 CV compared to the H(2p) peak near 4 cV. The high

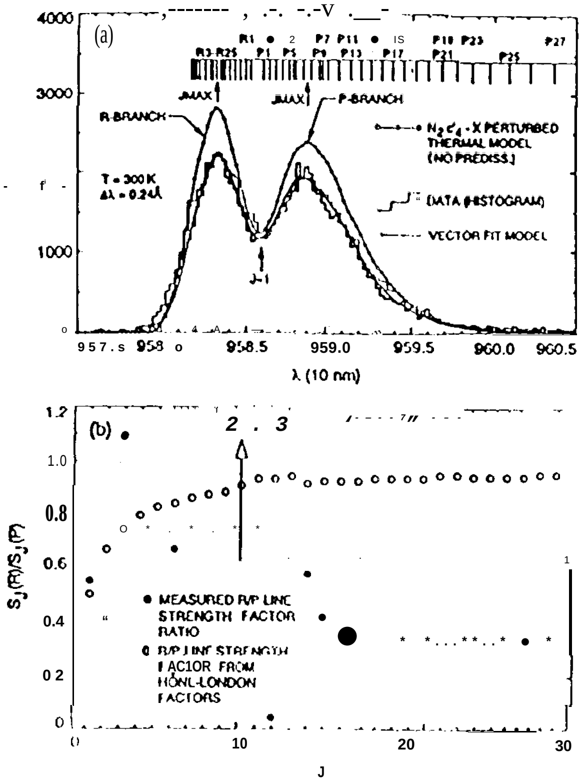

Figure 3. a) Measured spcctrum of the $N_2(c_4'-X)$ (0,0) hand excitcd by 100 cV electrons and two model band spectra and b) mcasured R/P line strength ratio.

kinetic. energy fragmcnts rcsult from dissociation through a series of repulsive curves which involve doubly excitcd electron orbitals.

5.0 EXPERIMENTAL RESULTS FOR $N_2(c_4'$-X) (0,0) BAND AT 959 Å

We report analysis of the rotational of the $N_2(c_4$ "-X) (0,0) band at medium resolution $\Delta\lambda$= 0.25 A. At this resolution the P- and R- branches are separable and has allowed a derivation of relative transition strengths of the upper state fine structure. Figure 3a shows the $N_2(c_4'$-X) (0,0) band rotational envelopes excited by 100 eV electrons at 300 K. The immediate result of the model analysis was that the upper rotational levels in the two branches deviate from Honl-London factors as shown in Fig. 3a for the case of no predissociation.

The breakdown of the Honl-London factor relationship requires the interference of the c_3 $^1\Pi_u$ state. When interference between states occurs the P/R line strength ratio can vary drastically as a function of rotational quantum number. The measured line strength ratios (R/P) is shown in Fig. 3b. For low J the deviation from the unperturbed ratio is small. The loss to predissociation takes place at J > 4. The determination of the predissociation fraction depends on two assumptions: 1) low rotational levels have no predissociation loss and 2) the interference with the c, $^1\Pi_u$ state introduces negligible variation in transition moment. Our estimated value of the predissociation yield at 300 K is 15%. The general absence of a detectable (0,0) band in the Earth's thermosphere may be explained by the significant predissociation at the high temperatures (-1000 K) and the radiative transfer effects at the large optical depths of 10^4 between source and satellite.

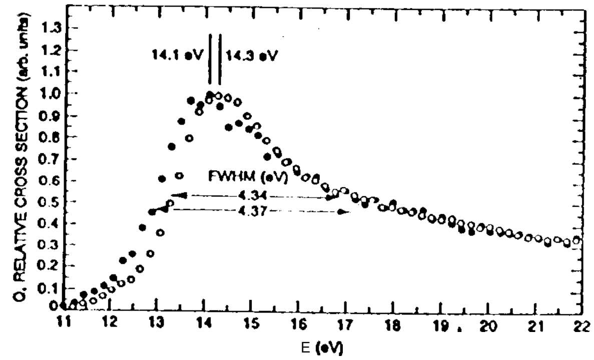

Figure 4. The relative cross sections of the N_2 2PG (0,0) (solid circles and (1,0) (open circles) bands in threshold region.

6.0 N_2 SECOND POSITIVE BAND SYSTEM

The emission cross sections and collision strengths for the (0,0) and (1,0,) bands of the 2PG arc shown in Fig. 4. The threshold structure can be explained without secondary collisions. The most intense structure can be attributed to decay of negative ion resonances directly to the C-state since cascade from the E-state is small. The 3159.4 A (1,0) band excitation function closely matches the (0,0) band. The half-width of the two bands arc shown. The absolute cross section for the 2PG(0,0) band is determined by comparing to the N_2^+(3914 A) first negative band system at 40 eV [14]. We obtain a cross section of 1.07 x 10^{-18} cm^2 at 40eV.

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